# A Visual Interface Diagram For Mapping Functions In Integrated Products

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# A VISUAL INTERFACE DIAGRAM FOR MAPPING FUNCTIONS IN INTEGRATED PRODUCTS

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## Abstract

In product development there is a recognized tendency towards increased functionality for each new product generation. This leads to more integrated and complex products, with the risk of development delays and quality issues as a consequence of lacking overview and transparency.
The work described in this article has been conducted in collaboration with Novo Nordisk on the insulin injection device FlexTouch® as case product. The FlexTouch® reflects the characteristics of an integrated product with several functions shared between a relatively low number of parts.
In this article we present a novel way of visualizing relations between parts and functions in highly integrated mechanical products. The result is an interface diagram that supports design teams in communication, decision making and design management. The diagram gives the designer an overview of the couplings and dependencies within a product that can be used to estimate higher level consequences when making design changes. The diagram has further been used as a basis for evaluating the criticality of internal parts and functional organs.

**Keywords**: Functional Modelling, Robust Design, Decision Making, Design Change Management, Complexity

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## 1 INTRODUCTION

Many companies experience that market competition forces them to increase the number of functions for each new generation of products, in order to increase the perceived costumer value.

This paper focusses on a mechanical single use product from the medico industry, where cost, robustness and design for manufacturing (DFM) considerations are challenged by the increased number of functions. Often the means for additional functions or features are integrated into existing solutions if that is somehow possible (Howard et al, 2013). For single use medico products high volume production is furthermore likely to push the business case towards the optimization of individual parts, and integration of more functions into one part to reduce the production and assembly costs. Therefore, the platform design and modules are likely to be designed to ease production and assembly processes, and will not necessarily reflect the embedded product functionality.

This kind of product architecture is seen in Novo Nordisk insulin injection devices such as FlexTouch®, where a strict control of product variants and internal chunks/modules is maintained, but where the individual modules do not necessarily represent isolated functionalities. The FlexTouch® is a highly integrated insulin injection pen and has been used as case product throughout the article to demonstrate the use and the benefits of the proposed novel visualization tool.

The integration of more functions into one part leads to products that become more integrated in nature, leading to difficulties in the development process. For highly integrated products the communication about the design becomes more difficult and demands a deeper understanding of the product, while consequences of design changes become harder to predict. There seems to be a need for stronger links between functions, modules and parts in the development process, keeping track of interlinked part-function relationships and visualizing complex products for supporting design and decision making (Pedersen, 2009). The design structure matrix (DSM) is a powerful and common tool to map dependencies across complex products (Eppinger et al, 2012) and to manage change propagation (Clarkson et al, 2004), (Keller et al, 2005). However, for visualization and communication purposes it has been shown that matrix-based approaches have limitations in practice and visualizations “embedding shapes and contours of real parts and products” are judged to be more practical (Gebhardt et al, 2014).

In this paper we present a novel way of visualizing functional relationships and interfaces in highly integrated mechanical products by adapting the interface diagram proposed by Bruun et al (2014). The developed tool increases transparency in system relations for project managers and development engineers in their daily work, enabling them to make better design decisions. Consequences of design changes can be detected more easily and discussions can be based on the criticality of the affected functions. In the case that a change can be realized in different parts, the parts with the least interference with critical functions can be chosen. At the same time the tool provides a link between the platform concept of “modularization” and the robust design concept of “part coupling degree” and mapping of functional surfaces.

## 2 SUPPORTING THEORY

The theoretical background presented in this section provides the foundation for the proposed interface diagram for highly integrated products. The work builds upon the Theory of Domains (Andreasen et al, 2014) and Theory of Technical systems, and is an addition to exiting theory on interface diagrams (Bruun et al, 2014) and functional allocations in modular products.

According to the Domain Theory a product can be described by its *function, property, structure* and *behaviour*:

- The *function* of a product describes its ability to perform a desired effect. There will typically be an acceptance level of how well a product fulfils the function.
- A product can be described by its *properties* which are quantifiable measures such as measuring accuracy, weight, stiffness etc.
- The *structure* of the product is a description of the physical elements that make up the product.
- The product’s *behaviour* describes what the product does, as a result of the way the functions have been realised. It can generate heat, vibration, noise etc.

A function is realized by an organ: that is the elements of a physical product that realize a certain function. An organ is also denoted “functional organ” which will be used interchangeably. The relationship between functions and organs are often modelled in a functions-means tree where the organs are the means to obtain the desired product functionality.
When moving from a theoretical solution towards a functioning product, some elements might be a part of several organs at the same time, thereby making the link between product structure and the function-means tree less operational. In this case the product has become integral.

## 2.1 Integrated and modular products

When a product’s function or sub-function is realized in a way where its organ is separated from the rest of the product structure and does not contribute to the realization of other functions, it can be thought of as a module. A modular product architecture can be described with the following characteristics (Ulrich and Eppinger, 2012)

*“A Modular architecture has the following two properties:*

- *Chunks implement one or a few functional elements in their entirety.*
- *The interactions between chunks are well defined and are generally fundamental to the primary functions of the product.“*

Modular products are theoretically easier to model in relation to their functional structure and organs, as there is a correspondence between the two modelling levels. For highly integrated (characteristically mechanical) products it is not possible to ascribe the physical realization of a function to an organ that is separated from other organs, as one chunk might contribute to the realization of several other functions.

Integral architecture is defined as follows (Ulrich and Eppinger, 2012):
*“An integral architecture exhibits one or more of the following properties:*

- *Functional elements of the product are implemented using more than one chunk.*
- *A single chunk implements many functional elements.*
- *The interactions between chunks are ill defined and may be incidental to the primary functions of the product.“*

For an integrated product the effect of design changes becomes more difficult to track, as there is a much more ill-defined correlation between the functional elements and the physical elements (Ulrich and Eppinger, 2012), meaning that the physical allocation of the function becomes difficult to track or define in the finished product. Modular product architectures are often preferred over integral architectures, as sharing of modules can e.g. increase transparency and promote reuse of modules in a product family, thereby reducing cost and complexity.
However, sometimes a product that fulfils the definition of an integral architecture will be produced in chunks that can be handled on the assembly line and reused as a standard element in a product family.
When elements are purposely grouped into chunks the phrase “module” is often used interchangeably with “chunk”. Harlou (2006) defines a module as *“one or more design units that are encapsulated into a module and that comply with module drivers”*, which is focussed on business synergies rather than functional organs.
It has been observed, that this kind of product architecture is seen in Novo Nordisk insulin injection devices such as FlexTouch®. The modules are optimized and designed from a production point of view and do not necessarily represent one isolated functionality.

## 2.2 Interfaces and interface diagrams

The control of interfaces plays an important role for the design of complex products, especially concerning design management of cross domain collaboration, modularization and products with a high level of functional integration.
The importance of interfaces in relation to assembly cost and complexity is further underlined by Van Wie et al (2001) who demonstrated through an empirical study that there is a relation between assembly cost and the number and type of interfaces in a modular product.

In the context of module interfaces Scalice et al. (2008) defined interfaces as: *"functional surfaces that unite two or more modules and carry out, at least, one of these functions: provide support, transmit power, locate part on assembly, provide location for other parts and transmit motion"*

The Interface Diagram (Bruun et al, 2014) has been developed to support the development of modularity in large complex product systems and to reduce development time. Bruun et al (2014) suggest a modelling formalism where components are identified and colour coded according to the functional system they belong to, and linked to associated components within and outside this system**.** With this overview and internal relations of interfaces, the components can be grouped into modules without losing track over the functional allocation within the product structure.

### 2.3 Robust design in early stage development

Robust Design (RD) plays an important role to ensure reliable and predictable products insensitive to variation and noise factors (Phadke, 1995), (Taguchi et al, 2005). Sources for variations can be categorized in manufacturing and assembly, load deformations, ambient conditions and variation over time (Ebro et al, 2012). In the case of a high volume production with an automated assembly line as for Novo Nordisk's FlexTouch® insulin pen the predictability and the consistent high functional performance are of crucial importance to maintain compliance and control costs due to scrap, quality control and redesign efforts. In general, many tools within robust design require a high degree of detail in the design before being applicable (Ebro et al, 2012; Krogstie et al, 2014). To increase robustness in early stage design Ebro et al (2012) suggests two concepts that will increase the robustness of mechanical products when applied in early stage design.

- Kinematic design: Ensure the correct mobility of mechanisms.
- Design clarity: Remove ambiguity in the part constrains realized by mechanical interfaces.

Both are directly linked to how the mechanical parts interface with each other, and are supported by both visual and schematic models. Design clarity is usually mapped by investigating the constraints given by each functional surface on a part, and is as such part centred in its visualization.
Suh (2007) proposes two general design axioms (Axiomatic Design) to facilitate a robust design, namely the independence and the information axiom. The independence axiom promotes the decoupling of the design, the information axiom the simplicity of the design. However, as described earlier, strictly following these axioms is not always possible, e.g. for economical and assembly reasons as in the current case of the FlexTouch®. For the complex and integral design of this injection device it is therefore important to be aware and keep track of functional couplings and try to avoid these if possible. Suh (2007) uses design matrices to describe the mapping of the design parameters (DP) in the physical domain to the functional requirements (FR) in the functional domain. The functional requirements and design parameters are quantifiable by e.g. force and dimensions, which makes them directly related to the detailed design.

## 3 RESEARCH METHODOLOGY

The development of highly integrated and complex products challenges the design team in terms of communication about the product and the prediction of possible implications when changing the design. This leads to the following research question.

*How can the communication and the design change management for the development of highly integrated and complex products be supported?*

The research has been carried out as a case study on Novo Nordisk insulin injection devices to find a new effective way of visualizing integrated products and improve design management tools.
The article builds upon the case product FlexTouch®, but the tool has also been applied and evaluated on other injection devices currently under development. CAD-files, design documentation and other relevant case data have been supplied by Novo Nordisk throughout the project.

The goal has been to develop a supporting tool for the design team of highly integrated products to be able to clearly communicate about the product and its functions and to manage design changes with respect to implications on other parts and functions. An evaluation of the tool has been carried out through interviews with stakeholders within internal Novo Nordisk departments for mechanical engineering. The applicability and usefulness has been of main concern.

## 4 INTERFACE DIAGRAM FOR INTEGRATED PRODUCTS

The interface diagram (Bruun and Mortensen, 2012) seems well suited for large complex systems with one dedicated role for each component, and provides a way to map functional organs and components in relation to modules (see schematic in Figure 1). The diagram emphasized the type of interface, e.g. cooling, hydraulic or mechanical interfaces, as the case product makes it meaningful to assign components that are a part of e.g. the hydraulic system, which can be viewed and handled separately in the PDM system.

However, the interface model is not directly applicable to give the same overview on highly integrated products as the FlexTouch® insulin injection device with few components (less than 25), where each component can be a part of as many as 4-5 functional organs. On prefilled insulin injection devices, the level of integration has the following implication: One component cannot be ascribed to one, but rather several functional organs. Therefore it is not possible to map each component with a distinct colour assigning it to one functional organ, as in the modelling formalism of the interface diagram by Bruun et al (2014). The level of detail needs to be on part-function and part-feature level rather than on part-module level to represent the high level of integration. The goal is therefore to adapt the interface diagram to visualize highly integrated products in a way that makes it easier to track functions and couplings for the purpose of a better communication and tracking of implications of changes on other functions.

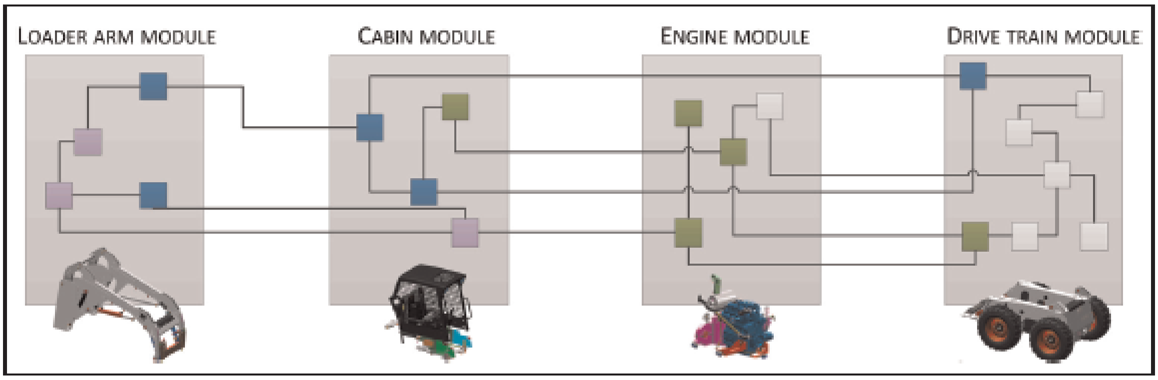


*Figure 1. Components in a modular context for the example of an excavator (Bruun et al, 2014)*

### 4.1 An interface diagram adapted for integrated products

Integrated products with few parts and many coupled functions as the insulin injection device under investigation require a more function driven representation of interfaces and dependencies. In that respect the interface diagram proposed by Bruun and Mortensen (2014) was adapted to allow and reflect parts contributing to multiple functions and again different modules for assembly purposes.

In Figure 2 the adapted interface diagram is applied to the FlexTouch® insulin injection device. The organs are illustrated to the right of the interface diagram with boxes containing a picture of the components that make up the system in the CAD model.

On the interface diagram itself, each component is displayed as a black box on its own, contributing to several organs (and thereby functions). A light grey box encapsulating several parts indicates if several components are grouped into an assembly module. To ease the interpretation of the diagram, the components should preferably be placed relative to each other in a 2D representation that resembles their actual arrangement in the product. The identified organs are mapped on the diagram by coloured lines between the components that contribute to the organ. In that way the functional organs within the product can be visualized even for highly integrated products. As presented earlier, several definitions

of interfaces exist, and it should be considered based on the product type, what interfaces to map on the diagram. For the case product it has proven to be suitable to omit some of the interface types with passive characteristics. Though considered an important functional surface when evaluating part mobility, the functional surfaces related to the “provide support”-functionality by the interface definition of Scalice (2008), are left out on this modelling level. Based on Tjalve (1979), they are not considered a part of the functional structure of the part. They are rather a result of constraining the active elements in a way that obtains the desired mobility and keeps free spaces for moving parts, handling etc.
This representation improves the overview of functional couplings throughout the insulin injection device. In the case of a design change in one or multiple parts, all affected functions can be determined. The same holds for the case if a new function or feature needs to be integrated.

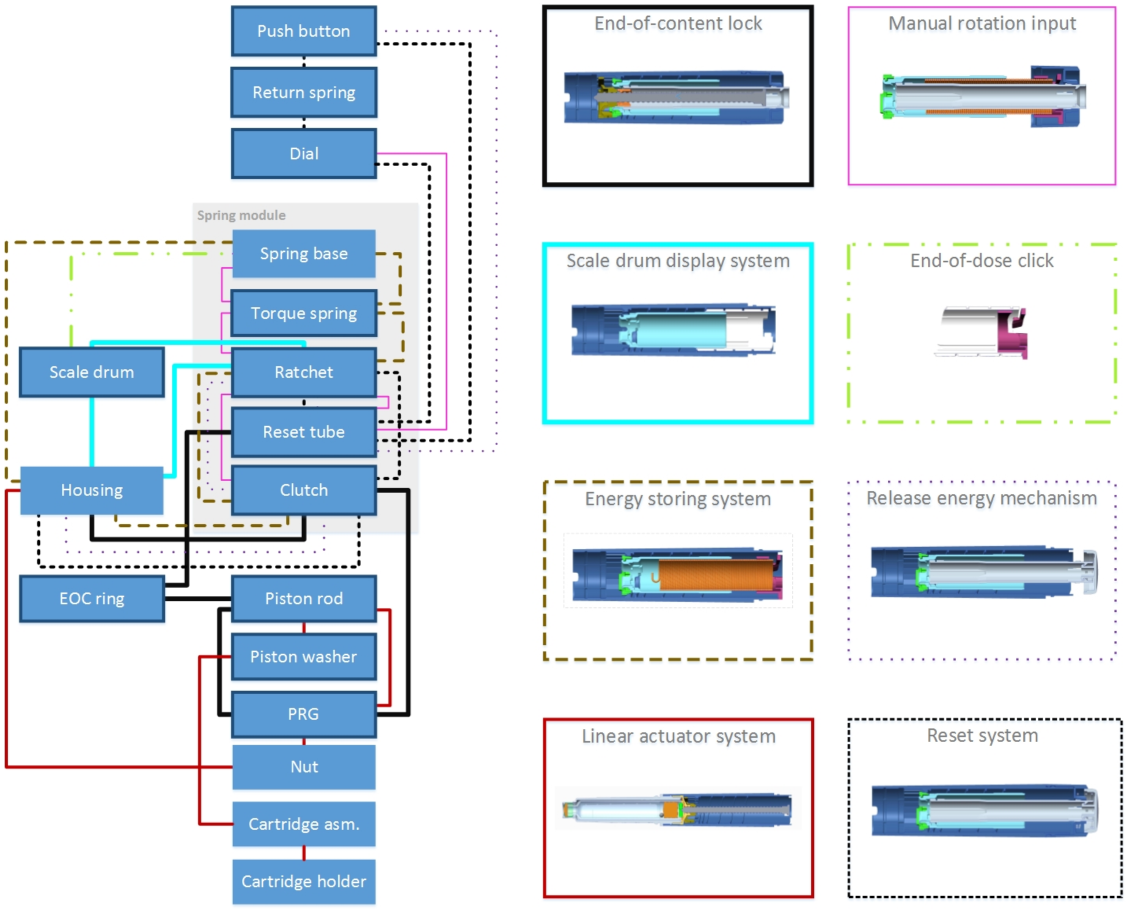


*Figure 2. Interface diagram for integrated products – FlexTouch®*

## 4.2 Opening up the black box of the components: A direct link to functional surfaces

Until now the parts have been depicted as “black boxes” with no distinct shape that interfaces to other parts. Opening of the black box of the components, the functional organs can be linked directly to part-part interfaces consisting of identified functional surfaces. This is an important factor when continuously working on the robustness of subsystems and interfaces, while maintaining the overall functional overview across a complex product.
An example from the *Reset tube* within the FlexTouch® is shown in Figure 3 including a schematic overview of the component as well as a description of functional surfaces on the actual part. The functional surfaces in the CAD model are coloured to highlight their importance. In some situations where a part is coupled to several functions, the functional surfaces could be coloured in the same colour as the related function in the interface diagram to emphasize its affiliation. The detailed view of the part could be visualized directly as a part of the main diagram or be presented on a separate document concerning part details, as shown in Figure 3. The necessary level of detail on the main diagram will be case specific and dependent on the individual project and the overall product complexity.

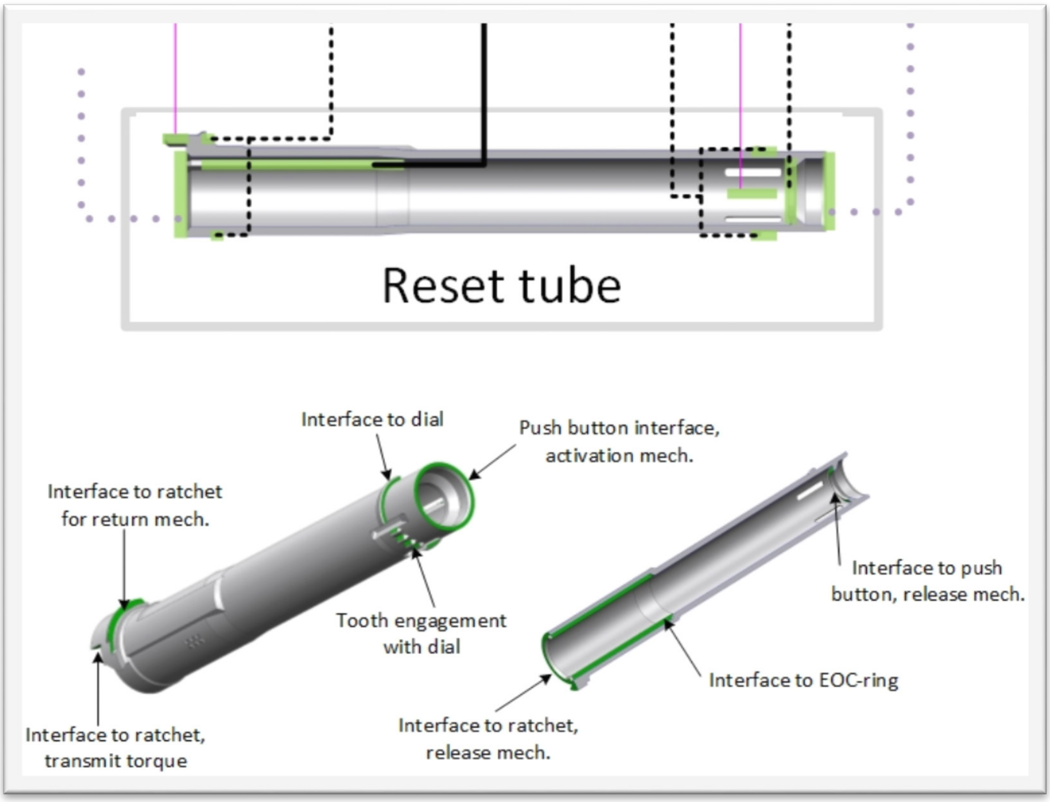


*Figure 3. Linking the functional surfaces to the functional overview*

## 5 EXTRACTING DATA FROM THE DIAGRAM

This section will give examples on how the visually presented information from the proposed diagram can be transferred to design and decision matrices to further improve the foundation for decision making in the design process.

### 5.1 Coupling degree of the design

Matrix-based representations of part and function dependencies are well established and widely used for further analyses of complex designs (Eppinger, 2012). Design matrices and Design Structure matrices are examples. The data can directly be read off the adapted interface diagram. The coupling between parts and functional organs can be determined for the whole product, for early stage designs where functional requirements and designs parameters might not yet be clarified. An overview of the coupling for the overall design could be a valuable indicator for comparing concepts in early stage design to foresee issues linked to functional integration and complexity, which are usually discovered later in the development process.

### 5.2 Coupling and relative importance of functions

In a development project of an insulin injection device, not all functions are considered equally important. There are many possible criteria for rating the relative importance of the functions, but some of the obvious indicators that a function within an insulin injection device should have higher priority are:

- The functional organ is directly linked to patient safety.
- The perceived customer value from the function might be very sensitive to changes.
- The output of a function is highly sensitive to changes in a design parameter.
- A function that is difficult to realize, e.g. because of a new technology or a complex organ.

As a tool to handle coupling and differentiated importance of functions, a decision matrix can be derived from the diagram that quantifies the criticality of changing certain parts or functional organs. The relative importance of each functional organ can be decided by e.g. an expert evaluation or

FMEA. Such a matrix is shown in Figure 4. The horizontal and vertical scores in the decision matrix are the basis for highlighting parts and functions that are critical and demand special attention when affected by design changes.

- Horizontal: Part coupling perspective on the system. Highlights parts that are linked to many and/or important functions. The part score is calculated row wise and sums up the scores of the functional organs that a particular part contributes to.

- Vertical: Functional organ coupling perspective. The score is calculated column wise by multiplying the number of related parts with the importance score of the functional organ.

Figure 4 shows exemplarily a decision matrix for the FlexTouch® insulin pen. From the horizontal scores it can be read off that the Housing, Ratchet and Clutch, with a score of 12, 10 and 8 respectively, are the parts with the highest integrated criticality level. That means that changes to these parts should be carefully considered and different solutions be chosen if possible. A look into the detailed part view with the visualization of the functional surfaces as described in section 4.2 can help to further clarify the impact of a proposed change.
The vertical scores summarize the criticality of the single functional organs. In the underlying example the "Linear actuator system" has the highest criticality score (21). Changes affecting this organ should be well considered and checked.

| **Organ/ functional system** | EOC lock | Manual rotation input | Scale drum display | EOC click | Energy storing system | Release energy | Linear actuator system | Return mechanism | |
|---|---|---|---|---|---|---|---|---|---|
| **Importance** | **1** | **2** | **3** | **1** | **2** | **2** | **3** | **1** | |
| Push button | | | | | | 1 | | 1 | **3** |
| Return spring | | | | | | | | 1 | **1** |
| Dial | | 1 | | | | | | 1 | **3** |
| Spring base | | 1 | | 1 | 1 | | | | **5** |
| Torque spring | | 1 | | | 1 | | | | **4** |
| Scale drum | | | 1 | 1 | | | | | **4** |
| Ratchet | | 1 | 1 | | 1 | 1 | | 1 | 10 |
| Reset tube | 1 | 1 | | | | | | 1 | **4** |
| Housing | 1 | | 1 | | 1 | 1 | 1 | 1 | 12 |
| Clutch | 1 | 1 | | | 1 | 1 | | 1 | 8 |
| EOC ring | 1 | | | | | | | | **1** |
| Piston rod | 1 | | | | | | 1 | | **4** |
| Piston waser | | | | | | | 1 | | **3** |
| PRG | 1 | | | | | | 1 | | **4** |
| Nut | | | | | | | 1 | | **3** |
| Cartridge asm | | | | | | | 1 | | **3** |
| Cartidge holder | | | | | | | 1 | | **3** |
| | **6** | 12 | **9** | **2** | 10 | **8** | 21 | **7** | |

*Figure 4. An example of coupling and relative importance on FlexTouch®*

## 6 DISCUSSION AND EVALUATION

The presented adapted interface diagram was derived from the interface diagram from Bruun et al (2014) and modified to support design management and decision making when working with highly integrated products. It provides a visual map of the product.
One of the main benefits of the diagram is the graphical and easy to understand representation of a complex and highly integrated product like the FlexTouch® insulin injection device. It enables an easy

visualization and allows discussions about the product without demanding knowledge about the mechanical details. Furthermore, in the case of design changes, affected parts and functions can be easily identified and communicated as well as trade-offs and implications be discussed. The diagram does not suggest ways to improve robustness, modularization, manufacturing or assembly of the product, but helps the design responsible to keep track of function-part relationships within the product when design characteristics are introduced as a result of the before mentioned considerations.
Robust design in concept development and early stage design has to a large extent been concerned with the details starting at part-part interfaces, moving down to functional surfaces, design parameters and process/material considerations. The proposed diagram opens up for a way to visualize and work with higher level robustness on a function-part level, while design clarity investigates the appropriateness of the mechanical interface itself. In order to exemplify how the diagram can be used to improve high level robustness, the data extracted from the diagram have been interpreted through the use of DSMs and the framework of axiomatic design. Though it is not expected to obtain a completely uncoupled design from a part-organ perspective, matrix-based representations can be used to quantify and balance the trade-off between complex parts that contribute to several functions and a higher number of simpler parts. We showed that the derived DSM can further be used to relate the coupling degree to the relative importance of functions to provide an overview supporting the design-management. Consequences of proposed design changes can be evaluated based on the criticality of the affected functions. Functional organs or parts with a high score should be monitored and evaluated more carefully and special attention should be paid when introducing design changes to their parts. When balancing demands for robustness against the need for integrating many functions in few parts within a compact product, there are no easy answers, but understanding the relationships of parts and functions eases the design management.

The adapted interface diagram described in this article has been applied to multiple insulin injection devices. It has been used in the development of a new device where a function was to be integrated. The method enabled the selection of the least critical and functionally coupled component as the point for integration. It also enabled the design team to see where the effects of making changes to the component would impact the product and what other parameters would need to be changed. The feedback from project managers and engineers have indicated that the presented diagram provided a new overview of functional mapping, that was previously handled more implicitly in development, and created great value, whilst being operational. The diagram is potentially applicable to other complex integrated products.

## 7 CONCLUSION

The article presents a novel interface diagram that supports the engineering design team of highly integrated products to visualize and communicate more easily about a complex design. Furthermore, in the case of a design change the diagram enables the design team to easily foresee affected parts and functions. Combined with a decision matrix, which can be directly derived from the diagram, educated decisions based on the criticality of affected parts and functions can be made.
The diagram has been applied to Novo Nordisk's insulin injection device FlexTouch® as a case study to evaluate the applicability and usefulness of the diagram. Interviews with engineers and project managers indicated good applicability and a great value of the diagram. It could be seen how the proposed diagram was used to avoid high level consequences by highlighting coupling and relative importance of internal functional organs when making design changes. The tool has been developed primarily for mechanical products, but is potentially applicable to mechatronic or other products with similar characteristics.

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